The Libyan Great Man-Made River Project Phase I
Paper 5. Conveyance pipeline system: construction

Proc. Instn Civ. Engrs Wat., Marit. & Energy, 1994, **106**, June, 179–189

Water Board
Water Panel
Paper 10455

Soo Hoon Lee and A. J. Woodford, BSc(Eng), CEng, FICE, FIWEM

Written discussion closes 16 August 1994

The Paper describes the construction work carried out for Phase I of the Great Man-Made River Project, Libya, by the Dong Ah Consortium, which is a joint venture of South Korean companies set up for the purpose. The project is of major size by any standards, carried out in site conditions which can be very arduous. The Contractor is responsible for final design as well as construction. Initial work included site investigations, the setting up of two major pipe manufacturing plants for prestressed concrete pipes, the construction of over 1500 km of haul roads and temporary construction camps. The work involved the manufacture, transport, and installation of over 1800 km of large diameter pipelines, a 4 million m^3 storage reservoir, power generation plant, well field equipment and facilities for the operations, support and maintenance of the project.

In the Paper, the organization of the consortium and the construction team, the supporting services required and the management of the staff which peaked at over 10 000 in country are discussed. In particular, the procedures involved in the transport installation and testing of the prestressed concrete pipelines are described.

Introduction

The Great Man-Made River Authority (GMRA) has promoted the development of groundwater resources in Libya.[1,2] Phase I of the project included resource development, construction of the conveyance system and the principal distribution systems to consumers. This Paper describes the construction of the conveyance system which is the major portion of Phase I of the Great Man-Made River Project (GMRP).

2. The principal feature of the project is the magnitude of the pipelines. The main conveyance pipelines comprise 1535 km of 4000 mm diameter prestressed concrete pipe. The wellfields have 394 km of pipelines from 1600 mm to 2800 mm diameter, 30 km ductile iron pipelines 600 mm in diameter, and connections to 234 wells. The water supply pipeline to the pipe manufacturing plant at Brega is 500 mm diameter ductile iron 150 km long. Prestressed concrete pipes are each 7·5 m long and 4000 mm units weigh up to 75 tonnes each.

3. While the problems of pipe manufacture and installation may not be untypical, the scale of the project and its components presented unusual problems and required exceptional levels of resources and organization.

Contractor

4. The GMRA invited tenders for Phase I of the GMRP in September 1981. Following tendering and subsequent negotiations, the contract was awarded to the Dong Ah Consortium of Seoul, South Korea (DAC). The extensive scope of the project and the construction schedule required a consortium of companies who could together provide the necessary expertise and very substantial resources. The consortium comprised

Dong Ah Concrete:
  pipe manufacture
Dong Ah Construction:
  haul roads, pipe installation and associated works, prestressed concrete pipe plants and aggregate quarries
Korean Express Company:
  international and in-country transport

Scope of contract

5. The main contract comprises Pipe Manufacture/Pipe Installation and Associated Works. Each part was negotiated separately and then combined into a single contract. The Owner (GMRA) had prepared preliminary designs for the project and the contract required the contractor to undertake final design, procurement and implementation of the works.

6. The main works comprised

- topographical survey
- geotechnical investigations
- final engineering design
- design and provision of two manufacturing plants for prestressed concrete cylinder pipes (PCCP)
- manufacture of all necessary PCCP
- provision of water supplies and establishment of quarries for pipe manufacturing plants

Soo Hoon Lee, Managing Director, Dong Ah Consortium

A. J. Woodford, Technical Director, Sir Alexander Gibb & Partners

- design and installation of conveyance system and wellfield pipelines and appurtenant structures
- provision and installation of wellfield equipment
- provision and installation of wellfield header tanks
- construction of Ajdabiya storage reservoir
- operation, support and maintenance (OS&M) facilities.

7. Certain items were furnished by the Owner. These included mainline block valves, control valves and large flow meters.

8. DAC/Itoh were also awarded a contract for the generating station at Sarir, which provides power to the wellfields at Sarir and Tazerbo. The construction and development of production wells was undertaken under separate arrangements. The construction of the end reservoirs at Sirt and Benghazi, and the distribution systems were also under separate contracts.

Terms of contract

9. The contract was let on a turnkey basis, to include engineering, procurement and construction. All components except pipelines were paid as fixed price lump sums. Pipe production, trench excavation and pipelaying were, however, on a remeasured basis. The total contract sum amounted to US $3·3 billion.

10. Funds for the contract were provided by the Libyan Government.

Organization

11. In addition to its own resources, DAC also required specialist engineering services to fulfil the design responsibilities. Subcontracts were arranged as follows

Design installation and operation, and advice on pipe manufacturing plant:
Price Brothers (UK) Ltd
Weybridge, Surrey
Design of PCC pipes
Price Brothers (UK) Ltd
Design of pipelines and ancillary works:
Sir Alexander Gibb & Partners, Reading
Geotechnical investigations:
Woodward–Clyde Consortium, Switzerland.

An outline organization diagram of the consortium is shown in Fig. 1.

12. A large number of offshore companies were also subcontracted to provide a wide range of materials and services.

13. The main subdivisions of the contractor's organization are

- administration
- pipe manufacture
- engineering
- construction
- planning and scheduling
- procurement
- QA/QC
- transportation.

14. In the early days of the project, liaison offices were set up in the USA. After the imposition of US sanctions in January 1986, these were withdrawn and offices in the UK were expanded to deal with the increased engineering work in this country. This provided direct communications with the Owner's consulting engineer, Brown & Root (UK) (Fig. 2).

Engineering

15. In general, the contract specification defined performance and quality requirements. All engineering design had to be approved by the Owner before manufacture or construction. Procedures were established for the submission of engineering design to the Owner and his consulting engineer for review, and approval. It was therefore necessary to take account of these revisions in the preparation of the engineering and construction schedules.

Construction schedules

16. The schedule for the design and construction of the project is shown in Fig. 3.

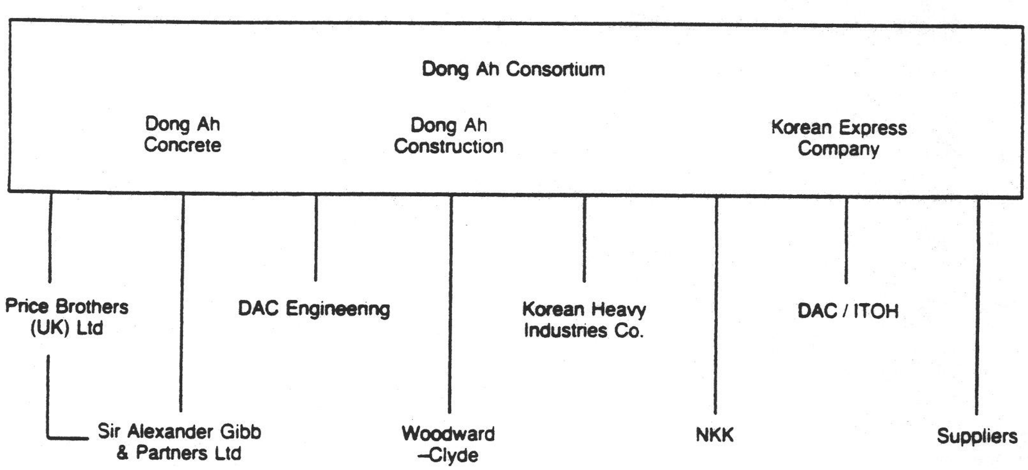


Fig. 1. Consortium organization

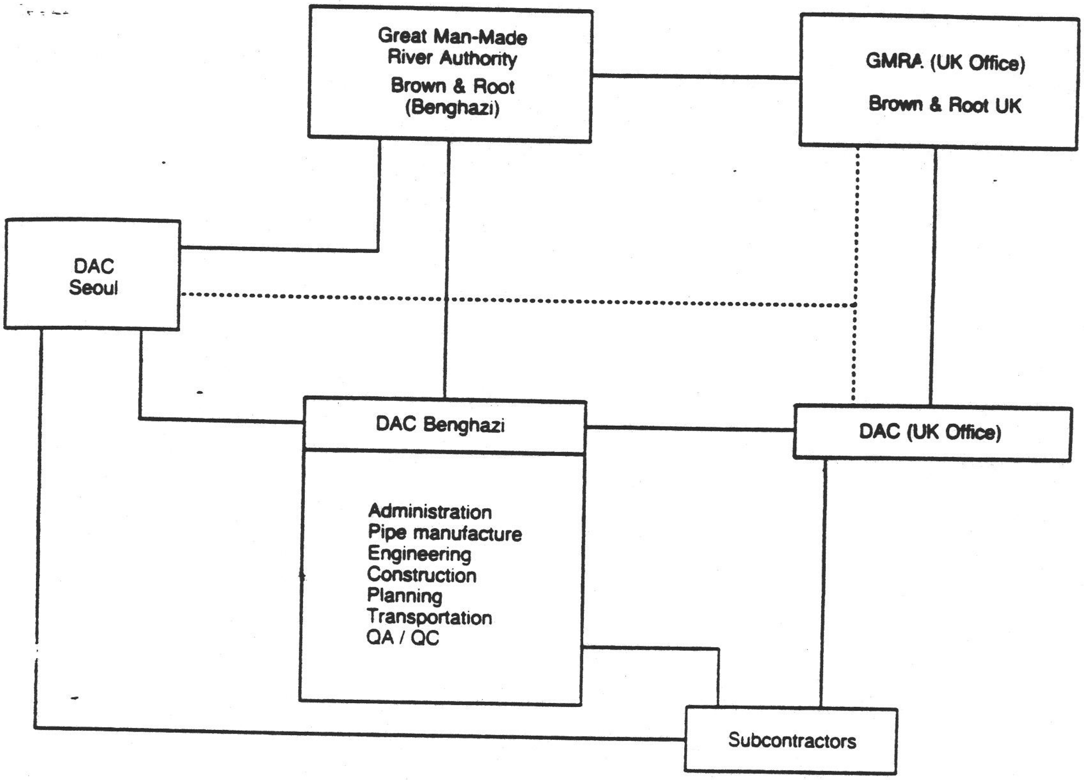


Fig. 2. Project organization

Climate

17. The project area principally has a low latitude tropical desert climate, but is less dry and has more of a Mediterranean type climate towards Benghazi. Average rainfall decreases from around 100 mm in the coastal region to nil in the southern section of the project. Prevailing winds are from the north and north-west, with periodic dust storms from the south. Temperatures are high in summer and cold in winter, with an annual average of about 20°C. The climatic conditions are summarized in Table 1. It was estimated that approximately 20 days of work would be lost each year in the desert areas as a result of sandstorms.

Resource requirements

18. The majority of equipment and materials were transported by sea through the ports at Benghazi and Brega. Expatriate staff were moved through Tripoli. Therefore, a substantial transport system was required. In country, the control of the project activities was from the headquarters camp at Benghazi, with transport and commercial aspects handled from the camp at Tripoli. The principal maintenance camp is at Ajdabiya, and facilities for pipe manufacturing plants were provided at Sarir and Brega. Independent camps were set up for construction spreads at 13 further locations, as shown in Fig. 4.

19. Workforce numbers varied according to the stages of construction of the works. From 1988 to 1990, for example, over 10 000 staff were employed in-country, and were almost entirely expatriate. About 3500 were employed at the pipe manufacturing plants and 3200 on pipe installation. Home leave for construction staff was provided at six month intervals.

20. Equipment levels were also very substantial, and included a wide variety of plant. For pipe installation, 65 excavators were

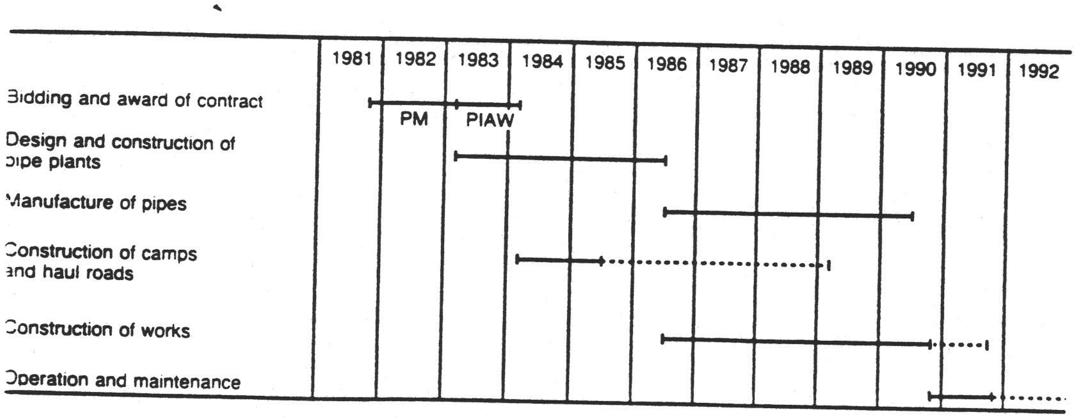


Fig. 3. Project schedule

Table 1. Climatic summary

Station		Tazerbo	Sarir	Ajdabiyah	Benghazi	Sirt
Temperature: °C						
Mean monthly:	max.	40·1	40·1	36·5	32·7	30·2
	min.	1·8	1·8	5·3	7·7	8·8
Extreme:	max.	47·3	47·3	46·7	41·7	46·1
	min.	−4·0	−4·0	0·0	0·0	1·7
Rainfall:	mm					
Monthly max.		10	10	197	109	133
Wind:	km/h					
Annual average		N 9·6	N 9·6	S 11·6	NE 19·6	S 12·9
Max. recorded		64·7	64·7	72·7	75·6	16·7

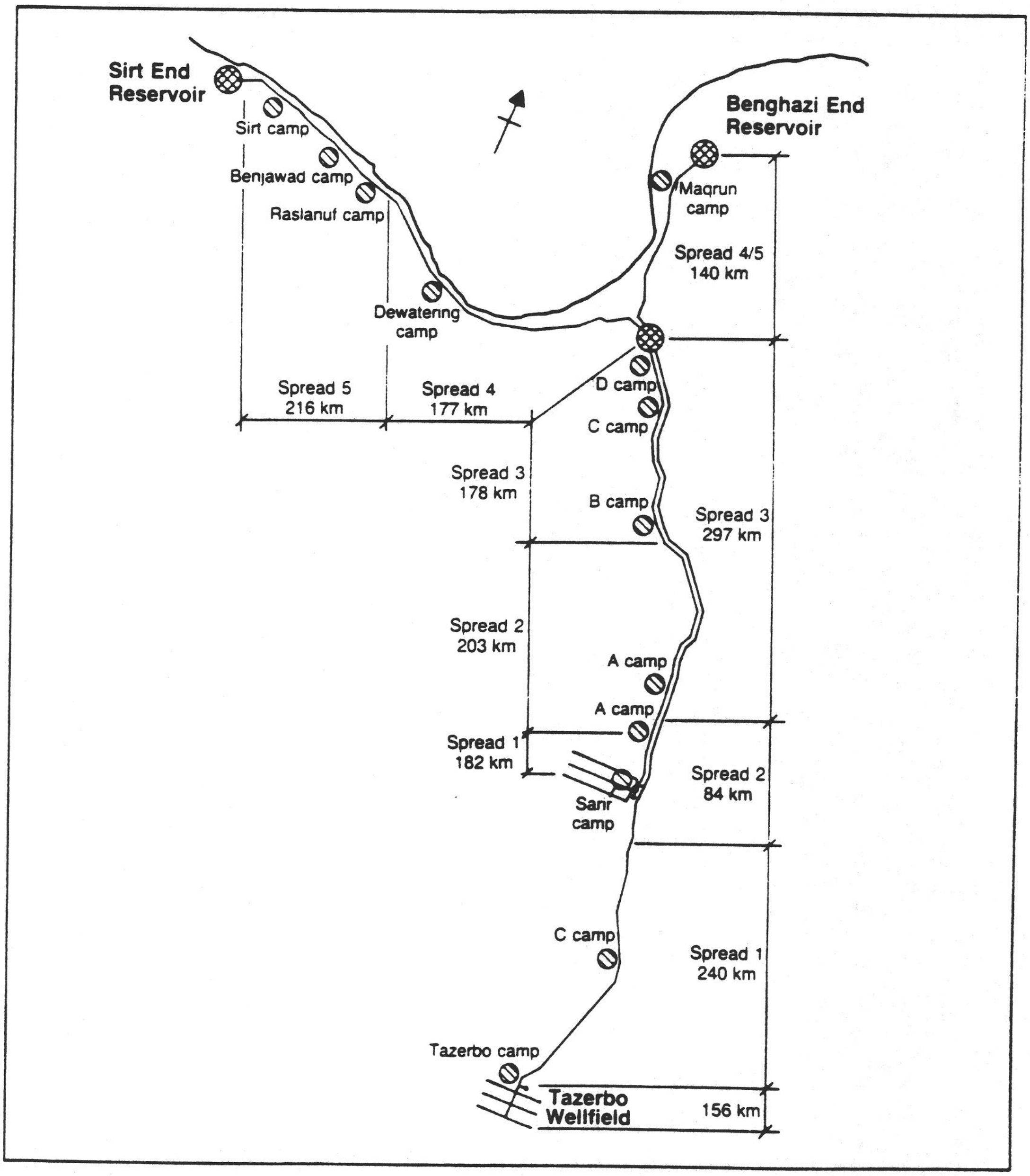


Fig. 4. Locations of construction camps

employed, including 17 at 7·6 m^3 and 39 at 1·2 m^3 capacity. Eighteen cranes were provided, which included six 450 t and six 100 t units. Altogether, 73 bulldozers were used. The total number of major mobile plant exceeded 1200.

Geotechnical investigations

21. An extensive geotechnical investigation was undertaken at an early stage to provide a information for the design and construction of the project. Its particular aims were to assess the following

- methods of excavation
- groundwater levels
- dewatering methods, where required
- slope stability of excavation
- subgrade condition beneath pipes and structures
- availability of suitable materials, particularly for pipe trench backfilling
- trafficability of the pipeline routes
- aggressivity of soil and groundwater.

22. For the main conveyance pipeline route, the investigation covered about 1150 km, including 290 boreholes, 120 trial pits, 240 seismic refraction surveys and 290 resistivity tests. This work was extended to cover the collector pipelines at Sarir and Tazerbo wellfields. Testing was carried out in a laboratory set up in Libya and also in Switzerland.

23. While the main geotechnical investigations gave adequate information for general interpretation and preliminary design, the intervals between test sites were considered too coarse for detailed assessment of pipe trench conditions. Accordingly, verification programmes were run ahead of pipelaying, and used to confirm or amend preliminary design.

Topographical survey

24. The setting out of the pipeline was the r onsibility of the Owner, who provided intersection points at all changes in direction. In between, for detailed design purposes, DAC field surveyors provided profile data at 50 m intervals.

PCC pipe manufacturing plants

25. The first major construction was the establishment of two manufacturing plants for prestressed concrete cylinder pipes at Sarir and Brega. The plant at Sarir has three production lines, two of which are dedicated to 4000 mm diameter pipes and the third line produces mainly the smaller sizes (1600 mm, 2000 mm and 2800 mm) required for the wellfield collector lines. The plant at Brega has two production lines both for the largest size only. These plants were designed for continuous operation, with a planned output of 44 pipes per day from each line. The plants are permanent installations, provided with staff accommodation and all necessary facilities. Stoner and Fookes[3] give details of pipe design and production.

Materials for pipe manufacture

26. Quarries were established near each of the manufacturing plants. At Brega, coarse aggregate is crushed from the limestone caprock, and fine aggregate comes from the Wadi Farrigh alluvium. The quarry at Sarir is in old river alluvium and produces rounded gravel of mixed rock types, with a small angular component that results from the crushing of oversize material. Fine aggregate is also from old river alluvium.

27. About 5700 t of coarse aggregate and 4300 t of fine aggregate are needed each day.

28. Cement is supplied mainly from the Libyan Cement Company in Benghazi; this is to ASTM C150 type II. Daily cement requirements amount to 2400 t. Transport from the cement factory to the pipe plants requires a fleet of 127 bulk cement carriers which, typically, each make one round trip per day.

29. Detailed discussion of materials and concrete control is given in Fookes, Stoner and MacKintosh.[4]

30. Water supplies at Sarir are from two boreholes drilled in the construction camp adjacent to the pipe plant. At Brega, however, no adequate supplies of good quality water were available. The nearest suitable source was near Jalu, where two boreholes were drilled. This required a pipeline to Brega, 150 km long, constructed of 500 mm ductile iron pipes.

PCC pipe production and transportation

31. The total numbers of prestressed concrete pipes required were as given in Table 2.

32. Each PCC pipe is 7·5 m long. The 1600 mm pipes weigh 12·9 t and the heaviest 4000 mm pipes weigh 75·4 t. To transport these from the manufacturing plants to site along the haul roads, a fleet of 80 t tractor/trailer units was provided, operating in five teams of 23 units each. The maximum round trip for a transporter was about 500 km and the total journey distance for the whole project was about 1·8 million km. Each tractor/trailer unit

Table 2. Total numbers of prestressed concrete pipes required

Diameter: mm	Pressure rating: bar	Quantity
1600	8	13 227
1800	8	3 867
2000	8	13 343
2800	8	1152
4000	6, 8, 10, 12, 14, 16	205 264
		236 853

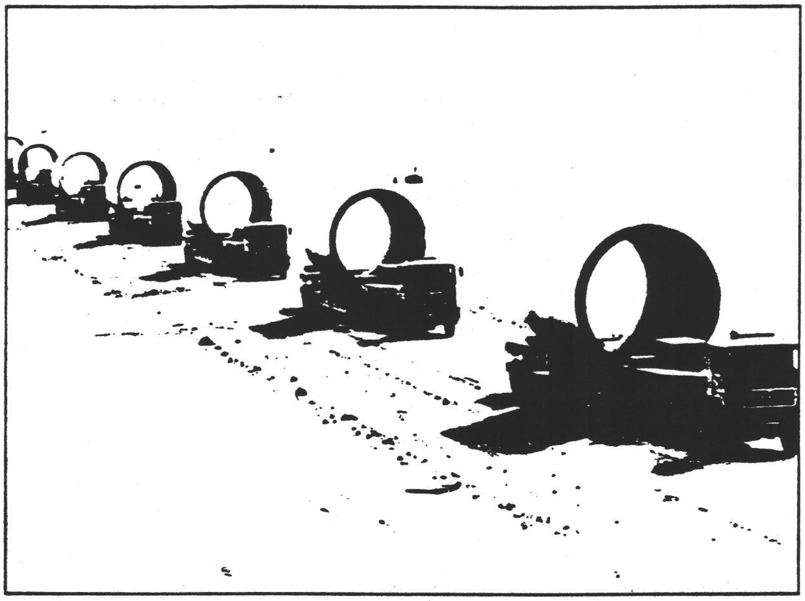


Fig. 5. Transport of pipes

could carry one 4000 mm or 2800 mm pipe, or three of the smaller sizes. A 250 t crane was provided for each team for pipe handling. The average transport speed was estimated to be 30 km/h loaded and 50 km/h unloaded. Units were normally operated 20 hours each day, with crews working 10 hour shifts. Fig. 5 shows a convoy of pipe transporters.

Pipe installation generally

33. The pipeline installation force in the field operated as five separate and self-contained teams or spreads. Each was provided with all necessary equipment and operated from its own base camp. Each spread was allocated two sections of pipeline to be constructed in sequence and the complete units were moved in between to suit the allocated sections. Most sections were about 150–200 km in length, as shown Fig. 4.

Right of way

34. Although pipelines were constructed generally in open country, it was considered necessary for limited rights of way to be allocated. These were arranged by the Owner and were set out to avoid existing roads, power lines, etc. Provision was made within rights of way for excavated trenches, spoil banks, construction haul roads and working areas. Allowance was made for duplicated pipelines where these were laid in parallel. The Contractor had to carry out all installation activities and dispose of surplus soil within these limits.

Fig. 6. Trench excavation

Haul roads

35. Pipelines are usually in open country, and construction haul roads were required for transportation of pipes, equipment, construction materials and the workforce. The use of public roads was not permitted. Haul roads generally comprised a 11·2 m wide graded sub-base with a water bound running surface. While haul roads have only a limited life, traffic is very heavy and the roads required constant maintenance. Some of the roads are still in use for transporting pipe from the manufacturing plants to Phase II of the project, south of Tripoli, and have been renovated recently for this purpose.

Site clearance

36. Very little site clearance was required. In some sections of undulating terrain it was necessary for ground levels to be graded, in order generally to reduce the cover over pipes, which was limited to 3·0 m. Some relics of minefields left from World War Two were found, and had to be cleared to provide safe working areas. Specialist teams cleared about 200 km of minefields.

Pipe trench excavation

37. Pipes were laid with a cover between 2·0 m and 3·0 m over the crown of the pipe. For a 4000 mm pipe, the floor of the trench was therefore about 7 m deep. Most excavation was carried out in dry conditions, using 7·6 m^3 excavators. However, considerable lengths required ripping or drilling and blasting. Also, trenches in high water-tables in wadis and sabkhat areas had to be dewatered. These are described later.

38. Excavated material was discharged into a hopper-spreader which operated alongside the excavator, as shown in Fig. 6. This screened the material to meet specification requirements for backfill and formed a continuous stock pile at a uniform distance from the pipe trench. Reject material was discharged beyond the stockpile. The trench floor was finished by a 3 m^3 long boom excavator and a bulldozer, using laser level control. Excavation was carried out at least five days before pipelaying, and any unsuitable soils arising from sandstorms was removed and the trench floor regraded before pipelaying.

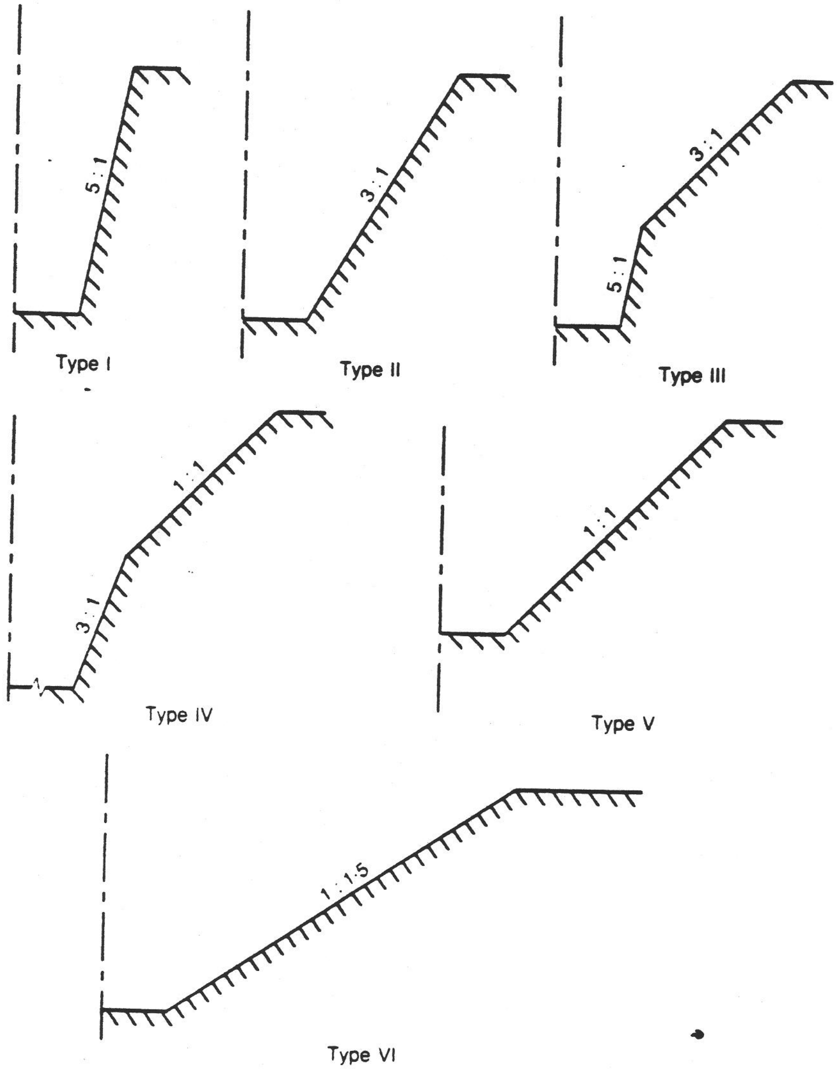


Fig. 7. Guideline trench profiles

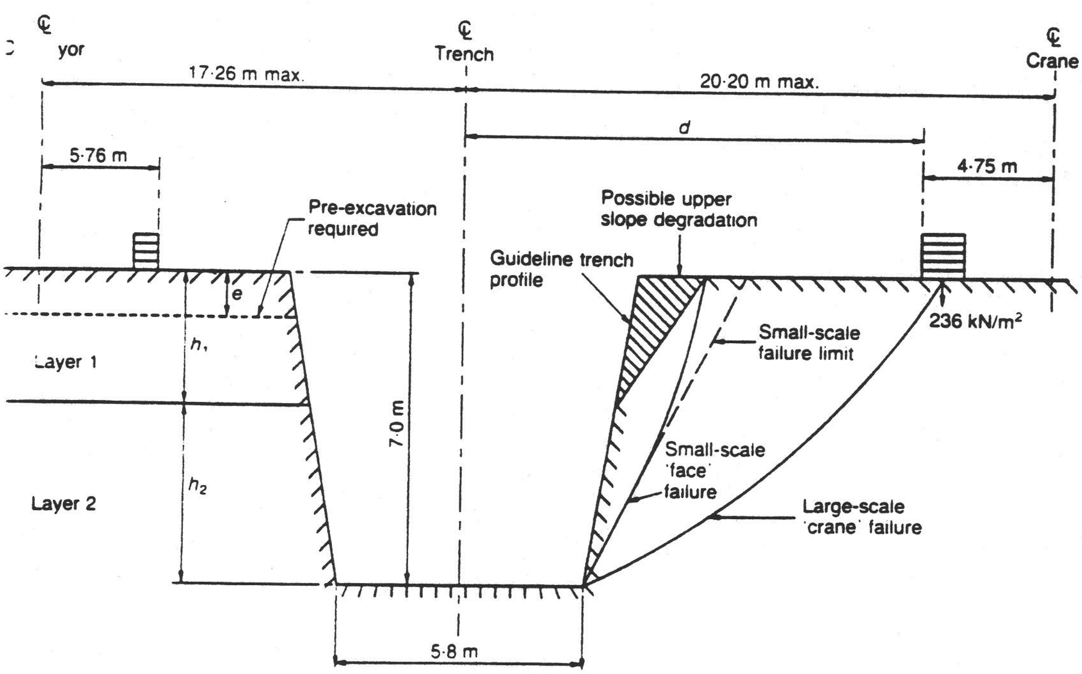


Fig. 8. Trench loading conditions

Excavation	Equivalent penetration resistance	Seismic velocity: m/s
Conventional equipment	Less than 100	400–900
Ripping required	Greater than 100	1000–2000
Blasting required		2000–3000

Table 3. Assessment of excavation methods

Pipe trench profile

39. It was vitally important that trench excavation should be kept to a minimum profile, consistent with the safety of the operations. Design of trench profiles took account of soil types, which varied from soft sand to rock, and also of the levels of the horizons encountered. Pre-construction design was based on data from the geotechnical survey. Further field testing was carried out during trench excavation and designs were modified as necessary as the work progressed.

40. The pipeline route was divided into sections of broadly similar characteristics and conservative worst case situations were defined. The loading conditions considered allowed for a loaded 450 t crane operating at a maximum distance of 20·2 m from the centre of the trench, and also a fully loaded soil conveyor not more than 17·26 m from the centre-line. The maximum loads on the equipment crawlers were 240 kN/m^2 and 120 kN/m^2 respectively.

41. Guideline trench profiles (Fig. 7) were developed on the basis that trenches were temporary works. Conditions considered for analysis to assess acceptable trench profiles included the following

(*a*) regrading of the generally loose or weakly cemented surface layers up to 1–2 m were likely to occur while the trench was shallow; these were not considered to be a threat to the overall stability of the trench (Fig. 8)

(*b*) small-scale failure of the trench face on steep slip circles involving up to the full depth of the trench but not affecting the equipment, and initiating 1·5 m or more behind the top of the slope; for this 'face' failure, a computed factor of safety not le: than 1·1 was required

(*c*) large-scale failure on deeper slip surfaces which would involve the crane (i.e. initiating within 3 m of the crane tracks); for this 'crane' failure, a computed factor of safety of not less than 1·2 was required, and it was assumed that the most critical 'face' failure had already occurred.

In situations where the required factor of safet for 'crane' failure could not be achieved, reduction of the ground level generally before excavation had to be considered (See Fig. 8).

42. Corroborative testing of conditions wa: carried out during construction to confirm the empirical relationships used in the guideline profile designs. Trench excavation was loggec generally at 500 m intervals. Where condition: were expected to change, full depth trial pits were excavated at close intervals. As shear strength determinations from the corroborativ testing programme and penetration test result: were collected, the correlations between SPT and cementation used in guideline design were reassessed. Design charts and tables were prepared to allow verification or adjustment of th required trench profiles. As a result of these precautions, substantial trench failures were avoided.

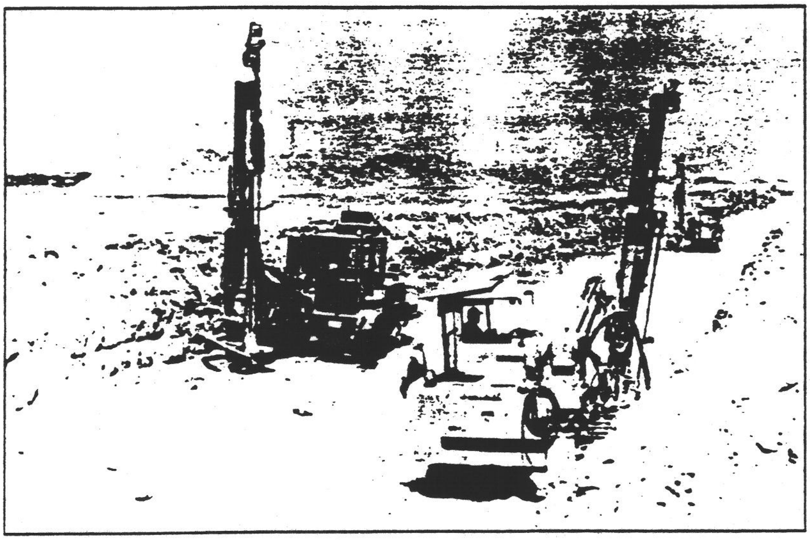


Fig. 9. Drilling for blasting

High groundwater conditions

43. For most of the pipeline routes, groundwater was at least 2 m below pipe invert level. The exceptions were at the major wadis between Sarir and Ajdabiya and, more significantly, in wadis and sabkhats between Ajdabiya and Sirt. Water levels were important in two main respects: first, the potentially corrosive effects of chlorides and water soluble sulphates; second, the problems of excavation of trenches in water-bearing ground. For the first, assessments were made from the geotechnical records of the lengths of pipeline where ground water levels were at or above pipe invert and also where the likely capillary rise of lower water levels would reach pipe invert. The amount of capillary rise was assessed on the basis of the soil types encountered. This assessment provided a basis for the extent to which pipes should be provided with a protective coating externally.

44. In more than 100 km of trench, groundwater was above pipe invert. The lengths involved varied from a few hundred metres up to 1·6 km, although between Ajdabiya and Sirt, lengths of 5·9 km, 6·0 km and 11·4 km occurred. Water levels were controlled by well point systems or by pumping from sumps, to permit dry construction.

Rock excavation

45. An assessment of excavation methods was made principally on the basis of seismic refraction measurements and standard penetration tests. These were classified as shown in Table 3. Ripping was carried out using hydraulic breakers and bulldozers. Where blasting was required, overburden was first removed down to bedrock level. For 4000 mm pipe trenches, drilling varied from three rows at 2·5 m centres to four rows at 1·7 m centres, depending on results of blasting trials and site conditions. The total length which required drilling and blasting was over 200 km (Fig. 9).

Pipe installation

46. Pipes were unloaded on to prepared ridges of sand or 'windrows' as shown in Fig. 10, using a 250 t crane. The pipes were set transversely to the pipe trench at a distance of about 44 m from the trench centre-line to give adequate working space. Pipes were placed in the pipe trench, using a 450 t crane at an outreach of about 20 m (Fig. 11). Each pipe was inspected before laying, and any units damaged during transportation were rejected. Local damage of coal tar epoxy coatings was repaired, and joint rings were fitted and lubricated before installation.

47. The line and level of the pipe bed were finally adjusted by bulldozer fitted with laser control. Pipes were lowered by the crane on wire rope slings and pushed home by a bulldozer fitted with a padded timber cross-beam.

48. Subsequent activities involved

(*a*) welding a bonding bar between the bell and spigot rings of each joint
(*b*) filling the internal space between pipe ends with cement mortar, by hand
(*c*) fixing a bandage, or diaper, externally over each pipe joint, and filling joint gaps with cement mortar.

Subgrade verification

49. The joints of PCC pipes are grouted with cement mortar and are therefore effectively rigid. Consequently, it is important that local variations in pipe foundation conditions should be avoided. Before pipes were installed, the exposed trench formation was investigated to ensure that it would adequately support the finished pipeline and that any vertical movements due to settlement or heave of the foundation would be within acceptable limits. This investigation was carried out after grading and proof-rolling of the trench floor.

50. In dry soils, standard penetration tests using dynamic cone penetration equipment (DIN 409, using a 10 kg weight dropping 500 mm) were carried out at 200 m intervals on the trench floor. Minimum values of 10 in the top 1 m of bed and 7 in the next 3 m were required. If these were not achieved, further compaction was applied. If the required criteria were not achieved, the trench would be over-excavated, backfilled with granular material and recompacted. Similar procedures were used in saturated coarse and fine grained materials, with appropriate adjustment of acceptance criteria. In clays, vane testing was required to assess shear strengths.

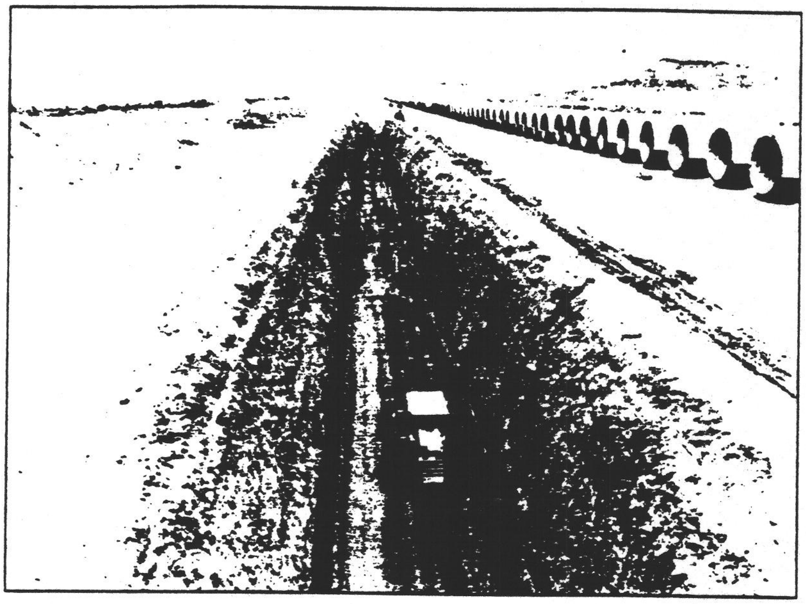


Fig. 10. Prestressed concrete cylinder pipe stringing

Bedding and backfill

51. Pipe bedding extended to a height of 0·125 × pipe outside diameter above the trench floor (Fig. 12). It comprised:

100% passing 50·8 mm (2 in) screen
95–100% passing 25·4 mm (1 in) screen
0–12% passing 200 mesh screen

and was compacted in layers to a minimum of 65% relative density.

52. From this level up to 300 mm above the pipe crown, zone I backfill comprised material

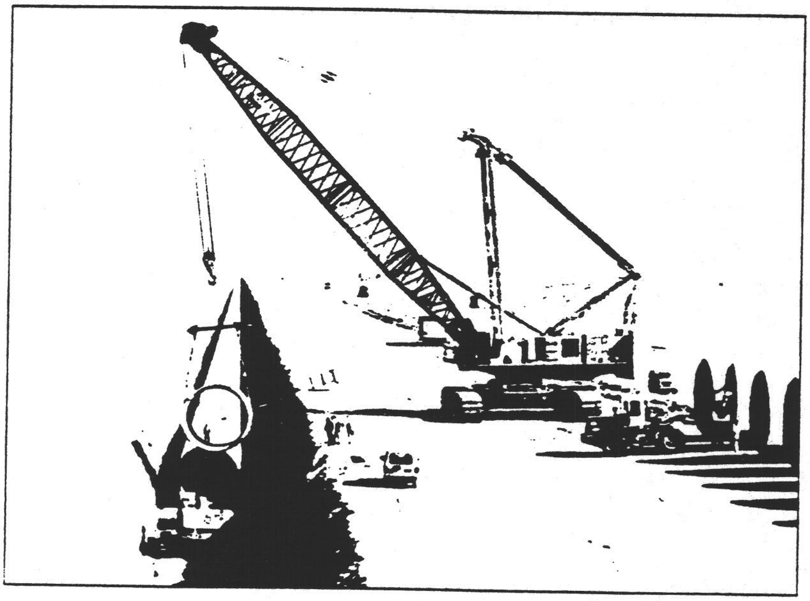


Fig. 11. Pipe laying

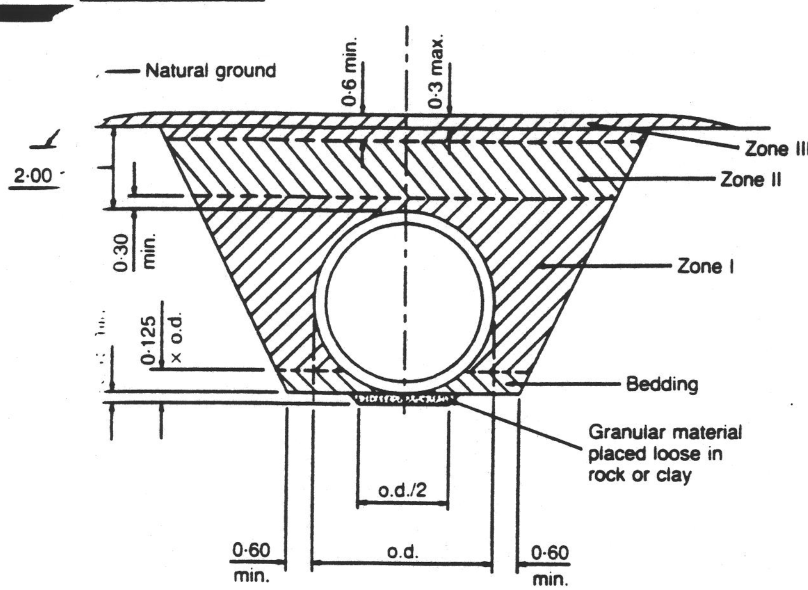


Fig. Installation of p

with a maximum size of 150 mm compacted to 65% relative density or 95% Standard Proctor. Above this level in zone II, a larger material was used, compacted to the same density. A surface layer, zone III, was 600 mm thick and extended to a maximum of 300 mm above natural ground level, having a grading similar to zone I.

53. Backfill around the pipe was placed by a conveyor on each side. Compaction in layers was carried out by vibrating rollers and a Hoe-Pac attached to an excavator (Fig. 13).

Pipelaying progress

54. Target progress rates for excavation and laying prestressed concrete pipes under normal conditions were set about 300 m per day, per spread, on the basis of a 26 day working month. In practice, an average rate of 300 m per day, with a maximum of 600 m per day, was achieved.

Hydrostatic testing

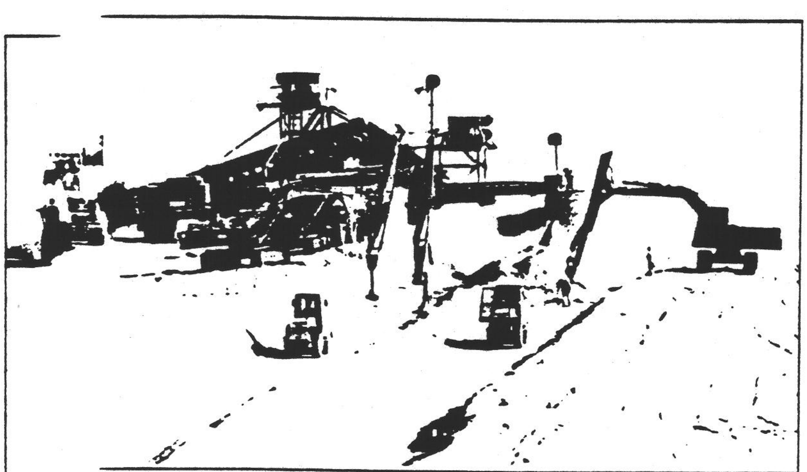
55. Sections of prestressed concrete pipelines were tested to between 100% and 120% of the design pressure of the pipes within the sections. Thus the maximum length of a test section was determined by the ground profile. The precise locations of test bulkheads were open to adjustment to suit local requirements and to simplify the transfer of test water. Substantial quantities of water were required. A section of 4000 mm pipelines, typically 8 km in length, required about 100 000 m^3 of water. Downstream of the wellfields, sections could be tested in sequence, and water was passed through bulkheads either by gravity or by pumping. Initially, lengths of up to 8 km were tested, but owing to difficulties in transferring water between sections, it was found necessary to extend some test sections up to a maximum of 40 km. The conditions specified for acceptance were

$$L = NDP^{1/2}/6520$$

where L is the allowable leakage in l/h (average over a 24 hour period); N is the number of joints in the length of pipeline that is being tested (which can be interpreted as length in metres divided by 7·5); D is the nominal internal diameter of pipeline in millimetres; and P is the average test pressure in bars (average pressure along test length of pipe measured on the centre-line of the pipe).

56. The apparent loss of water during a test was adjusted to take account of any temperature variation of the water in the test section. Tests were carried out after an extensive soaking period at a pressure not less than 1 bar. If the water loss during this period exceeded the allowable leakage, the section was not accepted for the pressure test. Pressure tests were carried out over a 24 hour period. Flow rates to maintain pressures were recorded and were considered to have reached stability when, subject to temperature correction, they reached constant or declining rates less than those specified for the sections under test. Following successful tests, bulkheads were replaced by adapter pipes. In all cases, the required test standard was achieved.

Fig. Backfill com on



Header tanks

57. The project includes three welded steel header tanks: one at Tazerbo Wellfield, and two at Sarir Wellfield. Each tank has a capacity of 170 000 m^3, and is 125·2 m in diameter and 14·6 m deep. Design is discussed in Kim and Greatbatch.[5] All materials were imported and transported overland to the job sites. The erection period was 20 months and, at peak, required a total labour force of 150.

Storage reservoir

58. The project included three storage reservoirs at Ajdabiya, Sirt and Benghazi, details of which are given in Samuel and Andrew.[5] However, only the first of these was

included in the pipeline contract. This is a circular earth bank reservoir, 900 m in diameter and lined with an impermeable membrane. The capacity is 4 million m^3.

Wellhead facilities

59. Well drilling and provision of submersible well pumps was the responsibility of the Owner. DAC was responsible for providing and installing wellhead pipework and power supply connections at all the 126 wells at Sarir and 108 wells at Tazerbo.

Power generation

60. The original contract was extended to include the supply and installation of a power generating station at Sarir. This is located near to the wellfield, about 400 km south of the coast. The installation comprises six dual fuel (gas/diesel) driven generators, each of 15 MW capacity.

Operating, support and maintenance facilities

61. In order to provide the necessary operating and maintenance services, operating support and maintenance (OS&M) facilities were established at the principal operating locations. A headquarters complex was established at Benghazi, with satellite complexes at Tazerbo Wellfield, Sarir Wellfield, Ajdabiya Reservoir, Sirt Reservoir and Benghazi Reservoir. In view of the distances involved, all facilities, except those at Benghazi, require residential accommodation for a total of about 420. The principal building works included: central headquarters; administration and operation buildings; workshops; warehouses; staff accommodation; personnel facilities; utilities. The total building areas exceeded 37 000 m^2 and were fully equipped.

Quality Assurance/Quality Control

62. In order to provide a finished product that complied with all of the requirement of the contract, a Quality Assurance/Quality Control (QA/QC) programme was established from the outset. The QA/QC organization was controlled from the project headquarters in Benghazi. The programme covered all activities of pipe manufacture and installation and associated work, including: design; document control; procurement; instructions, procedures and drawings; inspection and testing; process control; handling, storage and shipping.

63. Quality Assurance procedures were established for all aspects of the project, including relevant subcontracts, and audit programmes were carried out to ensure that all required criteria were met. These procedures were subject to periodic audit by the Owner's representatives.

Current status

64. Final commissioning awaits completion of the wellfields. However, limited initial supplies of water were made to Benghazi in September 1993.

65. As the sources develop and distribution systems are connected, the full-scale performance of the project will be assessed.

Acknowledgements

66. The Authors wish to express their thanks to the Great Man-Made River Authority for permission to publish this Paper. They also extend their thanks to the many colleagues, whose efforts in meeting the challenges of this exceptional project should not go unrecognized.

References

1. McKenzie H. S. and Elsaleh B. O. The Libyan Great Man-Made River Project. Paper 1. Project overview. *Proc. Instn Civ. Engrs Wat., Marit. & Energy*, 1994, **106**, June, 103–122.
2. Pim R. H. and Binsariti. The Libyan Great Man-Made River Project. Paper 2. The water resource. *Proc. Instn Civ. Engrs Wat., Marit. & Energy*, 1994, **106**, June, 123–145.
3. Stoner J. R. and Fookes P. G. The Libyan Great Man-Made River Project Phase I: manufacture of prestressed concrete cylinder pipe. *Proc. Instn Civ. Engrs*, Part 1, 1991, **90**, Aug., 853–879.
4. Fookes P. G., Stoner J. R., and Mackintosh J. H. The Libyan Great Man-Made River Project Phase I. Part 2: concrete technology of prestressed concrete pipe manufacture. *Proc. Instn Civ. Engrs*, Part 1, 1991, **90**, Aug., 881–919.
5. Samuel H. R., Andrew J. H. and Lee C. B. The Libyan Great Man-Made River Project Phase I. Paper 6. Storage reservoirs: design and construction. *Proc. Instn Civ. Engrs Wat., Marit. & Energy*, 1994, **106**, June, 191–202.
6. Kim Y. H. and Greatbatch D. The Libyan Great Man-Made River Project Phase I. Paper 4. Conveyance pipeline system: design. *Proc. Instn Civ. Engrs Wat., Marit. & Energy*, 1994, **106**, June, 165–178.